

## **Passive Estimation of the Ocean Seismoacoustic Environment by Extracting the Green's Function from Ambient Noise**

Karim G. Sabra

School of Mechanical Engineering

Georgia Institute of Technology

Atlanta, GA 30332

Phone: (404) 385-6193 Fax(404) 894-1658 E-mail: [karim.sabra@me.gatech.edu](mailto:karim.sabra@me.gatech.edu)

Award number: N00014-08-1-0140

<https://webwise.gtri.gatech.edu/osp/pad/cont?conNum=N00014-08-1-0140>

### **LONG TERM GOALS**

To develop the appropriate theoretical structure and subsequent processing tools and then to experimentally demonstrate utility of extracting the deterministic seismoacoustic properties of the oceanic environment from coherent processing of diffuse ocean ambient noise or scattered fields.

### **OBJECTIVE**

In the ocean, the dominant seismoacoustic noise source mechanism varies greatly across frequencies from ocean wave generated microseisms (0.05Hz-0.2Hz) to sea-surface noise (above 1kHz), including noise generated by human or biological activities. Though incoherent imaging with ocean ambient noise has been demonstrated (e.g. daylight imaging), a goal of this research is to use ambient noise, and even shipping noise, under certain conditions, to develop novel *coherent* imaging procedures such as tomography that typically require an active source or other noise based imaging methods in need of some coherence. Recent theoretical and experimental studies in ultrasonics, underwater acoustics and seismology have demonstrated that the time-domain Green's function (or impulse response)-TDGF-between two points can be obtained from the cross-correlation of ambient noise recorded at these two points [Fried et al., 2008]. These results provide a means for passive imaging using only the ambient noise field without the use of active sources. A potential scenario might include long-term deployment of ocean sensing systems requiring minimum power consumption, covert operations in hostile settings, or scenarios where active sources are limited by environmental regulations (e.g., Southern California).

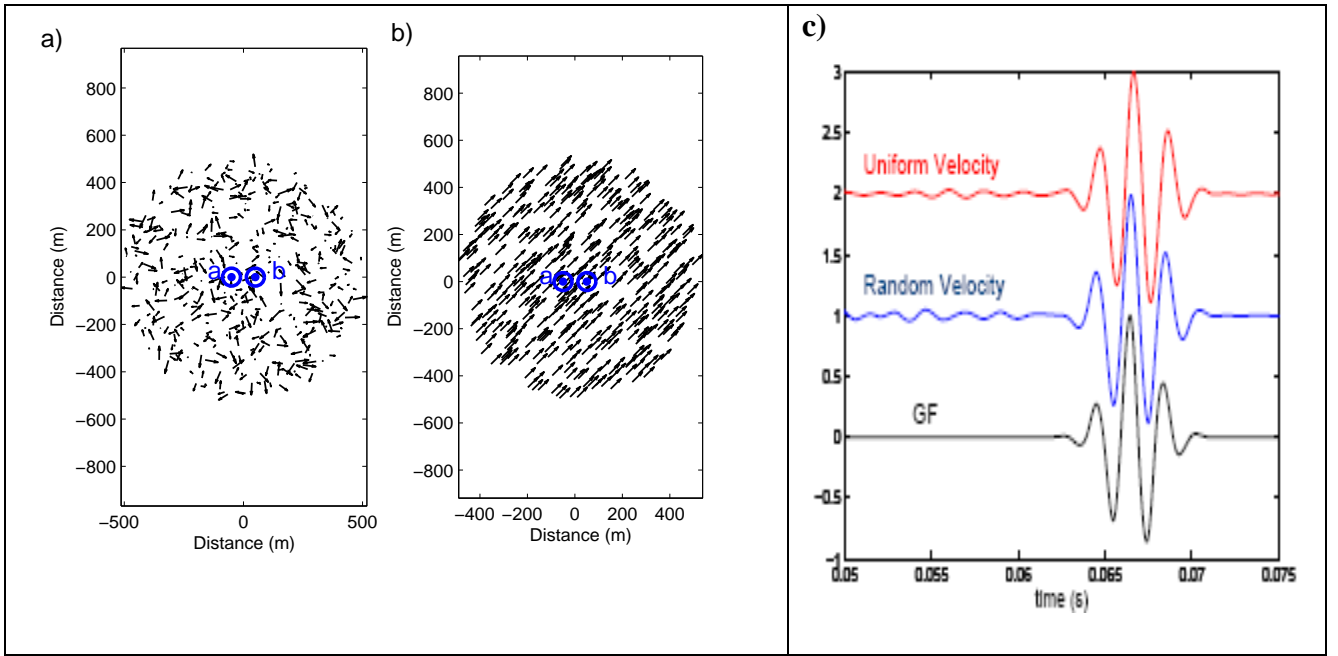
### **APPROACH**

The goal of this project is to develop the appropriate theoretical and signal processing tools for extracting the deterministic seismoacoustic properties of the environment from coherent processing of diffuse ocean ambient noise or scattered fields using various ocean sensing systems configurations. This project will mainly involves theory, propagation modeling, and data analysis oceanic ambient noise recorded in various coastal environments.

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>30 SEP 2009</b>		2. REPORT TYPE <b>Annual</b>		3. DATES COVERED <b>00-00-2009 to 00-00-2009</b>	
4. TITLE AND SUBTITLE <b>Passive Estimation Of The Ocean Seismoacoustic Environment By Extracting The Green's Function From Ambient Noise</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Georgia Institute of Technology,School of Mechanical Engineering,Atlanta,GA,30332</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>Code 1 only</b>					
14. ABSTRACT <b>To develop the appropriate theoretical structure and subsequent processing tools and then to experimentally demonstrate utility of extracting the deterministic seismoacoustic properties of the oceanic environment from coherent processing of diffuse ocean ambient noise or scattered fields.</b>					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT  <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES  <b>3</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

## WORK COMPLETED

Previous theoretical studies of the performance of this noise-based passive imaging technique have assumed that the noise sources remain stationary. We have investigated the influence of the motion of the noise sources on this passive imaging technique theoretically first in free space, using a stationary phase approximation. The results were then extended to arbitrary environments using first order expansions of the recorded wave field. Although the Doppler effect typically degrades the performance of standard wideband coherent processing schemes, such as time-delay beamforming for fast moving sources, it was found that the Green's function estimates extracted from ambient noise cross-correlations are not expected to be significantly affected by the Doppler effect, even when considering supersonic sources. Numerical monte-carlo simulations were conducted to confirm these theoretical predictions for both the case of subsonic and supersonic moving sources [Sabra, 2009].



**Fig 1. Schematic of the sources and receivers geometry used for the two-dimensional numerical simulations. A reduced density of sources was used to enhance visualization. Quiver (vector) representation of the velocity vectors of the moving sources (a) Random distribution in orientation and magnitude. (b) Uniform distribution (i.e. constant orientation and magnitude). (c) Comparison of the actual stationary free-space Green's function (noted GF) between receivers a and b to the noise cross-correlation function computed either for a random distribution( see a) or a uniform distribution (see b) of the velocity vectors of the moving sources.**

Free space simulations were conducted here. The sound speed  $c = 1500\text{m/s}$  and receiver separation distance  $L = 100\text{m}$  were selected to be representative of the top-view of an underwater acoustic experiment with a pair of hydrophones (noted a and b on Fig. 1). Furthermore, for simplicity, noise sources were assumed to be uncorrelated so that the contribution from each noise source to the total cross-correlation time function between the receivers could be added separately. The simulated short signals broadcast by each noise source were Gaussian-windowed sine pulses where  $f_c = 500\text{Hz}$  is the center frequency of the pulse their effective bandwidth was  $B = [100\text{Hz} - 900\text{Hz}]$ . Noise sources were

distributed (see Fig 1.a) up to an arbitrary distance of  $R < 500m$  away from the origin to account for the fact the contribution of the remote noise sources is in practice limited in range due to acoustic attenuation effects. A high density was used for the noise sources surrounding the receivers with approximately one source every  $5m^2$ .

The average location for the sources was the same for Fig. 1.a and Fig. 1.b, only their velocity distribution actually vary. Two cases of sources motion were investigated numerically by using either 1) a random uniform distribution of the individual source velocity vectors  $\mathbf{v}_s$  both in orientation (i.e. over 360 degrees variations) and in magnitude ( $0 < |\mathbf{v}_s| < V$  for varying value of the upper bound  $V$  (m/s)) (see Fig. 1.a), or 2) a uniform distribution of the source velocity vectors pointing all at a 45 degrees orientation and having all the same magnitude  $|\mathbf{v}_s| = V$  (see Fig. 1.b). Fig. 1.a could be representative of an accumulation over time of randomly distributed wind-generated sea-surface acoustic events (e.g. white caps). The situation depicted in Fig 1.b may occur in the vicinity of the hydrophones if a prevalent wind or swell direction exists and uniformly advects the acoustically active white caps.

Fig. 1.c illustrates that the main coherent arrival of the computed noise cross-correlation time-function between both receivers provides a close estimate of the direct arrival time of the actual Green's function  $tG = L/c = 66.6ms$  even for high value of magnitude  $V$  of the velocity vector, up to 50m/s, for both cases shown in Fig 1.a and Fig. 1b. Theoretical derivations are fully described in an upcoming publication [Sabra, 2009]

The main result of this study is that the coherent arrivals of the ambient noise cross-correlation function are predicted not to be significantly modified by the noise sources motion, even for supersonic noise sources under certain conditions. Hence, these coherent arrivals of the noise cross-correlation time function are expected to yield an accurate estimate of the *stationary* Green's function between the receivers, similarly to case of stationary noise sources as previously reported. The robustness to the Doppler effect of this noise cross-correlation process primarily results from its spatial directivity which emphasizes the contribution of the noise sources which cross the ray joining both receivers (i.e. the stationary phase regions). Indeed, when a moving noise source crosses those specific locations, the differential Doppler effect between the stationary receivers is minimal and thus resulting coherent timedelay is not significantly affected by the Doppler effect.

## IMPACT

It is conjectured that the results of this study could provide an upper bound to assess the performance of noise-based passive imaging in the presence of moving sources, especially at high-velocity. Hence, fast sources of opportunity (e.g. highspeed vessels, aircrafts) could potentially be used for noise-based tomography of the ocean seismoacoustic environment when using a stationary network of passive sensors, without requiring additional Doppler corrections in data post-processing.

## PUBLICATIONS

S.E. Fried, W.A. Kuperman, K. G. Sabra, P. Roux, "Extracting the local Green's function on a horizontal array from ambient ocean noise," *J. Acoust. Soc. Am.*, Vol. 124, EL183-188 (2008).

K. G. Sabra, "Influence of the noise sources motion on the estimated Green's functions from cross-correlations of ambient noise recordings between stationary receivers," Submitted to *J. Acoust. Soc. Am.* (June, 2009).